CHAPTER 3
CHANGES IN AMBIENT OUTDOOR SULFATE CONCENTRATIONS

This chapter presents the approaches used in this assessment to estimate the changes in ambient outdoor sulfate aerosol concentrations by location attributable to the Title IV required SO_2 emissions reductions. This chapter relies on available results from other analyses conducted for or by the U.S. EPA for estimates of changes in SO_2 emissions and changes in ambient sulfate aerosol concentrations. In this chapter, we briefly describe these other analyses and explain how we use the results in this analysis.

3.1 CHANGES IN SO_2 EMISSIONS

ICF Resources (1994) has prepared for the U.S. EPA estimates of current and future SO_2 emissions by location through 2010 for a Title IV implementation scenario and for a no Title IV scenario. The ICF Resources analysis focuses on the SO_2 emissions in the utility sector, where 85 percent of the Title IV required emissions reduction is expected. This health benefits assessment incorporates, without modification, the ICF Resources annual SO_2 emissions estimates for the eastern United States.

The analysis uses ICF Resources' Coal and Electric Utilities Model (CEUM). CEUM is a large linear programming model that develops least-cost compliance options across the utility industry in meeting SO_2 reduction targets. The model considers in detail the interaction between the demand for different types of fuels and the costs of supplying and delivering the fuels, as well as the interaction between utilities' marginal costs of compliance and the projected amount of allowance "banking."

Basic Features of CEUM

- set of interrelated models and databases for analyzing the coal and electric utility industries in an integrated way
- cost-minimizing linear programming model
- SO_2 emissions is one key output: others include NO_x emissions, environmental compliance information (e.g., compliance costs, coal market impacts, numbers of scrubbers used), power plant operational choices (e.g.. new plants built, fuel choice)
- incorporates technical and economic relationships of coal and electric utility markets
- high degree of resolution:
  - most generating units represented individually
  - detailed coal supply, transportation, transmission, and utility demand segments.

CEUM uses a series of selected economic, energy market, and utility sector assumptions. These assumptions play an important role in estimating emissions with and without Title IV, because factors such as substitute fuel prices, energy demand, and economic growth can all have significant effect on decisions by utilities about building new capacity or retrofitting plants for alternative fuel use. Emission levels are directly related to levels of electricity production, fuels used, and compliance options employed.

Figure 3-1 shows the ICF Resources estimates of utility SO_2 emissions with and without Title IV from 1990 through 2010. Maximum allowed SO_2 emissions are fairly well defined by the Title IV requirements. There is some uncertainty about how quickly the Title IV emission reduction goals will be met because there are provisions that allow utilities to bank unused emissions allowances and use them at a later time. It is uncertain how much banking the utilities will choose to do, but ICF Resources estimates that all banked allowances will be exhausted by 2010. Uncertainty also exists in predicting the specific location of emissions reductions because emissions allowances can be traded among emitting facilities.

Table 3-1 shows the ICF estimates of annual SO_2 emissions by state for 1997 and 2010, with and without Title IV. Both of the with Title IV estimates include an estimated response of utilities to the opportunities provided in the Title IV program to reduce emissions more than required in the early years of the program and to bank these as emission allowances for future use within a limited time period. The results of the with and without Title IV forecasts show that even with Title IV there are a few locations where SO_2 emissions are expected to increase slightly. However, there is expected to be a significant reduction in total emissions. In 2010, with Title IV, total SO_2 emissions from utilities in the East are expected to be about 7.7 million tons versus an estimated 16.8 million tons in 2010 without Title IV. The without Title IV emissions estimates do reflect emissions reductions expected due to other Clean Air Act Amendment requirements.

As noted in Chapter 2, there is more uncertainty in predicting what emissions would have been in the absence of Title IV than for the with Title IV scenario. Total emission limits are set by Title IV and utilities (as a group) are not expected to emit less than they are allowed under Title IV, because the Title IV limits are well below 1990 emission levels. In the absence of Title IV, there are some factors that would cause future SO_2 emissions to rise and some that would cause SO_2 emissions to decline. In general, economic and population growth results in greater demand for electricity, which may result in higher SO_2 emissions. At the same time, as older plants are retired and cleaner electricity generation processes are developed, SO_2 emissions per unit of electricity generated can be expected to decline. How emissions would change, therefore, depends on the relative significance of these different factors. ICF Resources estimates that in the absence of the Title IV requirements, SO_2 emissions from utilities would have risen slightly from 1990 levels. They predict a slight rise would have occurred between 1995 and 2005, and then a fairly flat trend through 2010.

Current SO_2 emissions vary considerably by location in the eastern United States in part because of significantly different amounts of high sulfur content fuels used in different locations. The reductions in SO_2 emissions expected as a result of Title IV are concentrated in areas that currently have the highest SO_2 emissions. Table 3-2 shows the ICF Resources estimates of the reduction in annual SO_2 emissions attributable to Title IV in 2010 by state for 31 eastern states. The last column shows the emissions reduction per capita in each state.

Figure 3-1
U.S. Utility SO_2 Emission Levels: 1990 through 2010

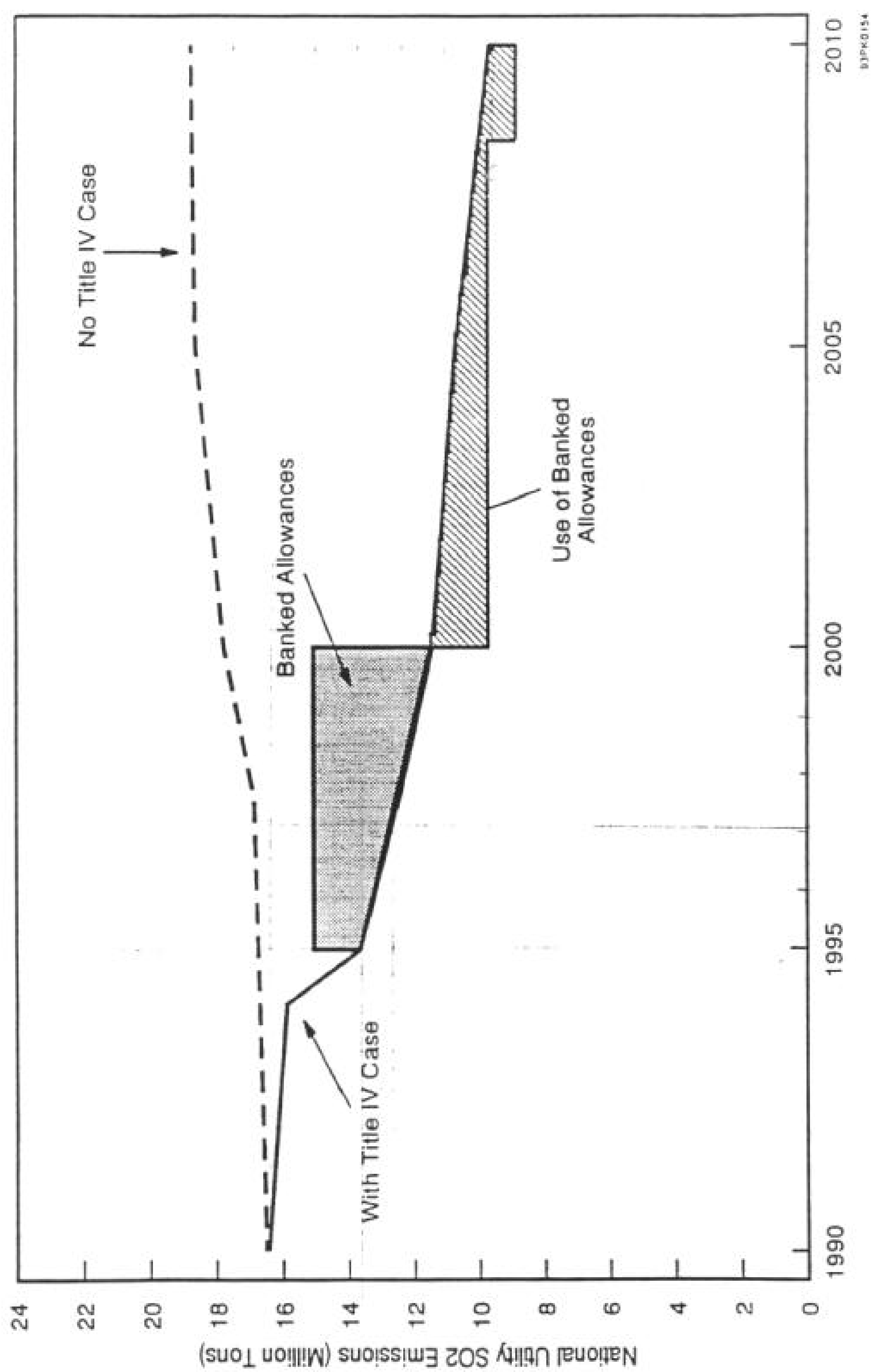


Table 3-1
EPA Forecasts of Annual Utility SO_2 Emissions (thousand tons) by State[1]

State	1985	1997 (with Title IV)	1997 (no Title IV)	2010 (with Title IV)	2010 (no Title IV)
Maine, Vermont, New Hamp.	87	43	43	46	54
Mass., Conn., R.I.	308	175	175	164	189
New York	413	309	338	259	346
Pennsylvania	1,174	991	1,120	625	1,178
New Jersey	102	102	131	115	164
Maryland, Delaware, D.C.	285	336	340	217	430
Virginia	131	233	225	159	264
West Virginia	951	629	965	569	1,085
North Carolina, South Carolina	499	754	719	547	866
Georgia	998	577	912	414	919
Florida	531	542	748	517	900
Ohio	2,217	1,187	2,455	690	2,399
Michigan	409	428	427	370	397
Illinois	1,045	637	901	460	1,199
Indiana	1,496	738	1,360	536	1,559
Wisconsin	380	269	248	180	397
Kentucky	783	531	817	386	967
Tennessee	802	574	920	297	1,074
Alabama	534	478	661	379	681
Mississippi	102	94	160	94	163
Minnesota	111	140	140	104	136
Iowa	198	185	245	139	266
Missouri	961	455	897	308	944
Arkansas	73	85	85	93	93
Louisiana	79	104	104	71	99
Total 31 Eastern States	14,672	10,596	15,137	7,740	16,769

[1] Emissions estimates from ICF Resources (1994).

Table 3-2
Estimated Reduction in Annual Utility SO_2 Emissions in 2010 Attributable to Title IV by State

State	Emissions Reduction in 2010 (1000 tons)[1]	Population 1990 (1000s)	Reduction per Capita (10^{-2} tons/person)
Maine, Vermont, New Hamp.	7	2,900	0.24
Mass., Conn., R.I.	25	10,306	0.24
New York	87	17,990	0.48
Pennsylvania	553	11,882	4.65
New Jersey	48	7,730	0.62
Maryland, Delaware, D.C.	213	6,054	3.52
Virginia	105	6,187	1.70
West Virginia	516	1,793	28.78
North Carolina, South Carolina	319	10,116	3.15
Georgia	506	6,487	7.80
Florida	384	12,938	2.97
Ohio	1,709	10,847	15.76
Michigan	27	9,295	0.29
Illinois	738	11,431	6.46
Indiana	1,022	5,544	18.43
Wisconsin	217	4,892	4.44
Kentucky	581	3,685	15.77
Tennessee	777	4,877	15.93
Alabama	301	4,041	7.45
Mississippi	69	2,573	2.68
Minnesota	31	4,375	0.71
Iowa	127	2,777	4.57
Missouri	637	5,117	12.45
Arkansas	0	2,351	0.00
Louisiana	28	4,220	0.66

[1] Emissions estimates from ICF Resources (1994). Projected 2010 reductions are the difference between emissions with and without Title IV.

It is clear that a large variability in emissions reductions by location persists even after accounting for differences in population. The largest reductions are in the Appalachian and Midwest regions.

3.2 CHANGES IN SULFATE AEROSOL CONCENTRATIONS

The pollutant of interest in this health benefits assessment is sulfate aerosol, which is a secondary pollutant formed in the atmosphere in the presence of gaseous SO_2 emissions and other atmospheric constituents. The location and amount of SO_2 emissions are two factors that determine sulfate aerosol concentrations. Other factors are weather conditions, wind speed and direction, and the presence and quantities of other elements in the atmosphere that interact with SO_2 to form sulfate aerosols.

For this analysis, we use results from EPA's Regional Acid Deposition Model (RADM), which include estimates of ambient sulfate aerosol concentrations for alternative SO_2 emissions scenarios. Chang et al. (1990) provide a detailed description of RADM, and Dennis et al. (1990, 1993) provide results of evaluations of RADM. Airborne sulfate aerosol concentrations are an intermediate result provided by RADM for the purposes of estimating the eventual deposition of acidic species. RADM reports results, including ambient sulfate aerosol concentrations, for grid cells 80 km by 80 km in size, over the entire area of the eastern United States. SO_2 emission rates by location, as estimated by ICF Resources, are an input into RADM. The RADM estimates used in this health benefit assessment are the ground-level sulfate aerosol (SO_4) concentrations for the following SO_2 emissions scenarios:

▸ Actual 1985 emissions, used to approximate conditions when the 1990 Amendments went into effect

▸ Estimated 1997 emissions with Title IV and banking

▸ Estimated 2010 emissions with Title IV

▸ Estimated 2010 emissions without Title IV.

The Regional Acid Deposition Model

The RADM is a comprehensive model of the atmospheric processes that lead to the formation and deposition of acidic species. The objective of this modeling system is to provide a scientific basis for estimating the change in deposition caused by large changes in precursor emissions. Specifically, the RADM is designed to (1) mathematically represent the nonlinear dynamics both of oxidant formation from precursor emissions of NO_x and VOCs, and of scavenging of sulphur compounds, and (2) mathematically represent the three-dimensional dynamics of transport, transformation, and deposition, including effects of cloud processes. The version of the model used for this analysis (Version 2.6) is designed to report this information on grid cells 80- × 80-km in size, over a domain that extends from east of central Texas to the south of James Bay, Canada, including all of Florida and southeastern Canada. This version of RADM uses six vertical layers from the ground to approximately 16 km in altitude. Version 2.6 has been corrected for some under predicting of sulfate levels that occurred with earlier versions.

The model operates on a mathematical frame of reference in which concentrations are specified as functions of time at fixed positions within the grid cells. The RADM uses the wind flow and precipitation simulated by a mesoscale meteorological model, called the MM-4, over an episodic period chosen to be 3 days. Modules of various chemical and physical processes involving the transport, transformation, and removal of pollutants are included in RADM and they utilize the meteorological simulations obtained from the MM-4. Because each run of the RADM represents a 3-day episode, a method to produce seasonal and annual estimates using a sample of episodic runs is required. Each episode is weighted according to its relative importance toward seasonal and annual wet deposition. RADM is run in each episode, and the results are multiplied by the weighing factors to produce seasonal and annual deposition calculations.

Figures 3-2 through 3-5 illustrate the distribution of the RADM sulfate aerosol concentration estimates across the eastern United States for each of the SO_2 emissions scenarios.

RADM results used in this assessment are summarized in Table 3-3. Table 3-3 gives the estimated reduction in median annual SO_4 concentrations for 1997 with Title IV and emission allowance banking versus the SO_4 concentrations under current (1985) conditions and for 2010 with Title IV versus predicted SO_4 concentrations without Title IV. These are ground-level SO_4 reductions for the 50th percentile of the annual distribution of estimated SO_4 concentrations. The results in these tables are the averages of the changes in the 50th percentile concentrations by state based on the results for the 80 km by 80 km RADM grid. Exposures and health effects are calculated at the grid cell level in this assessment, but averages for the states are shown here because the grid level data are too numerous.

The partial states at the western edge of the RADM grid, as shown in Figures 3-2 through 3-5 have been dropped from the quantitative assessment because the sulfate concentration changes expected in this area are small. The RADM grid also covers the southern parts of several Canadian provinces. Significant changes in sulfate concentrations are predicted as a result of the expected reductions in SO_2 emissions in the United States for Ontario and Quebec, so these have been included in the assessment. The portions of these provinces covered in the air quality model include the areas where the vast majority of the populations of these provinces live. The northern edge of the RADM grid is just south of the southern edge of James Bay.

3.3 MATCHING POPULATION TO ATMOSPHERIC SULFATE CHANGES

To calculate the human health benefits associated with the expected reduction in atmospheric sulfate aerosols concentrations, it is necessary to determine the change in ambient outdoor sulfate concentrations where people are. This requires an overlay of the population distribution on the RADM grid to match numbers of people to the estimated changes in sulfate aerosol concentrations.

For this analysis, we use the Geographic Information System (GIS) to match the 1990 population data from the U.S. Census (1990) and the 1991 Canadian Census to the RADM grid, and to estimate the populations in each relevant age group residing in each of the 1330 RADM grid cells. EPA provided us with the latitude-longitude coordinates for the center of each RADM grid cell. These were projected into lambert projected meters using standard parameters for lambert conformal projections of the United States. This gave us an orthogonal grid of points. We then used the THIESSEN procedure to draw grid cell boundaries equidistant between each pair of grid cell points.

Figure 3-2
RADM 50th Percentile Annual Sulfate Concentration ($\mu g/m^3$)
1985 Base Case

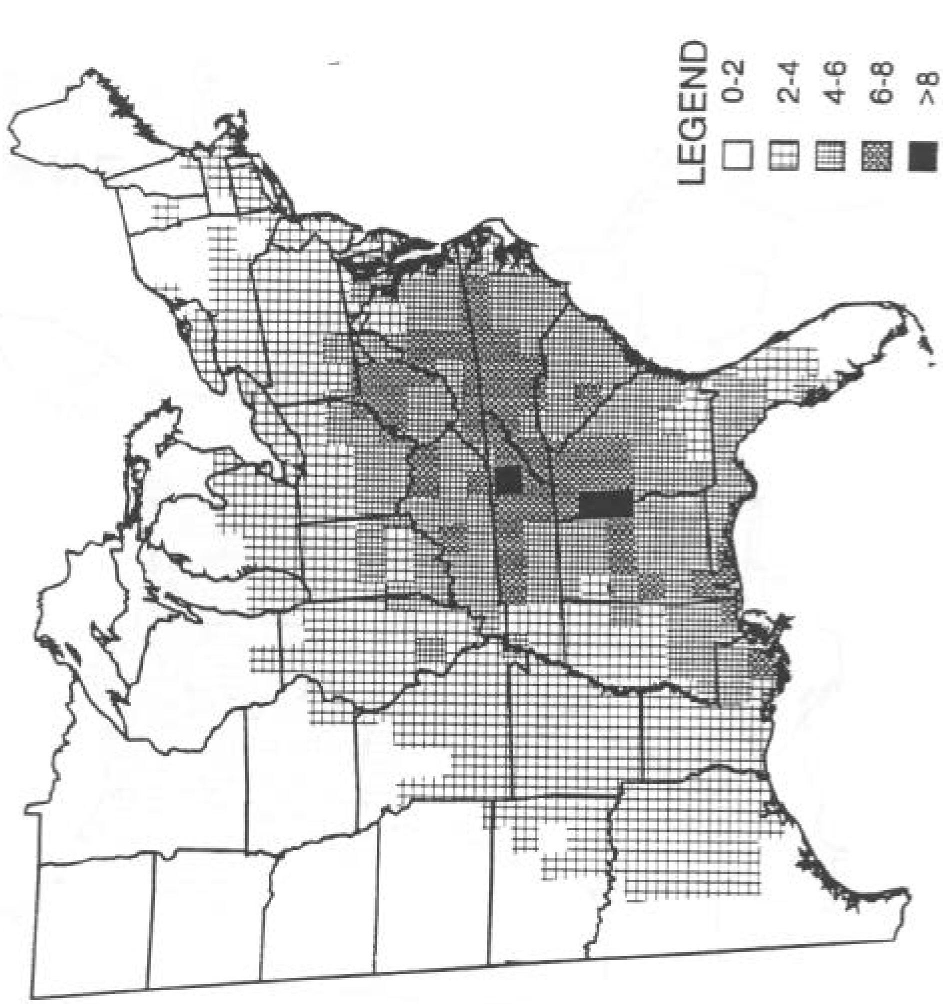


Figure 3-3
RADM 50th Percentile Annual Sulfate Concentration ($\mu g/m^3$)
1997 with Title IV[1]

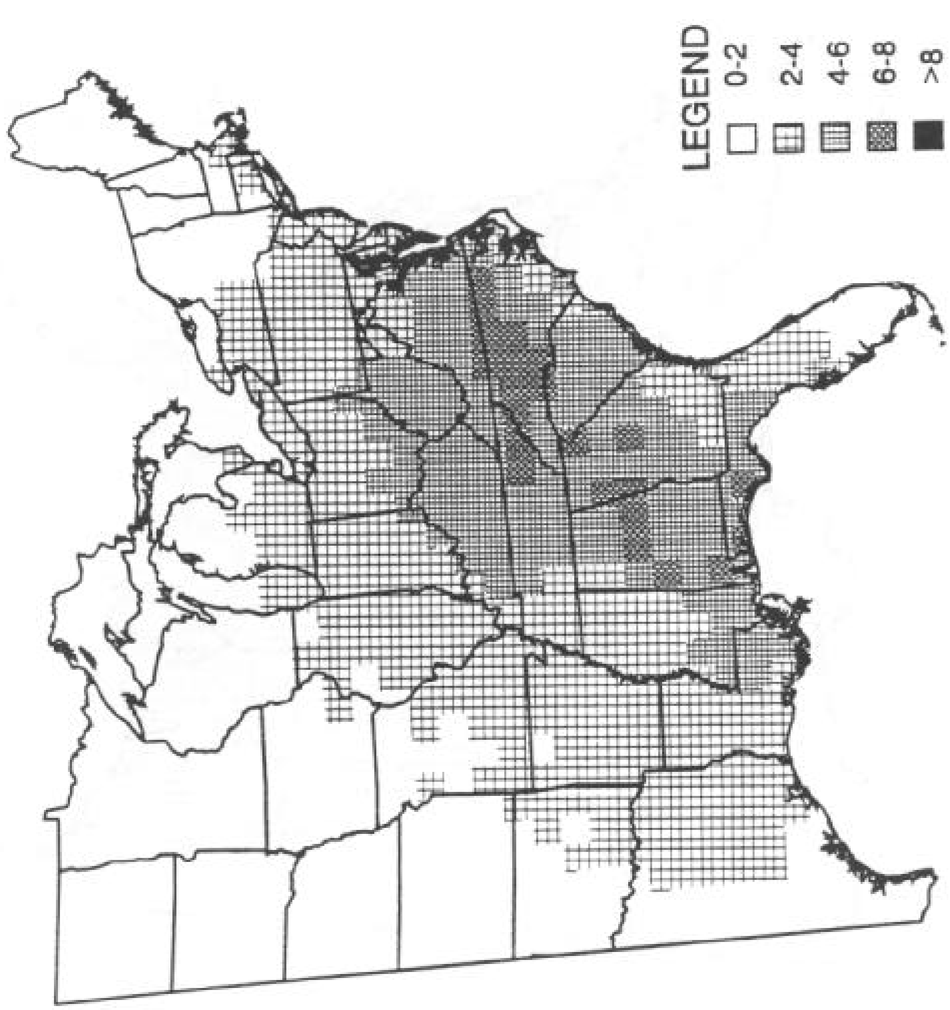


Figure 3-4
RADM 50th Percentile Annual Sulfate Concentration ($\mu g/m^3$)
2010 without Title IV

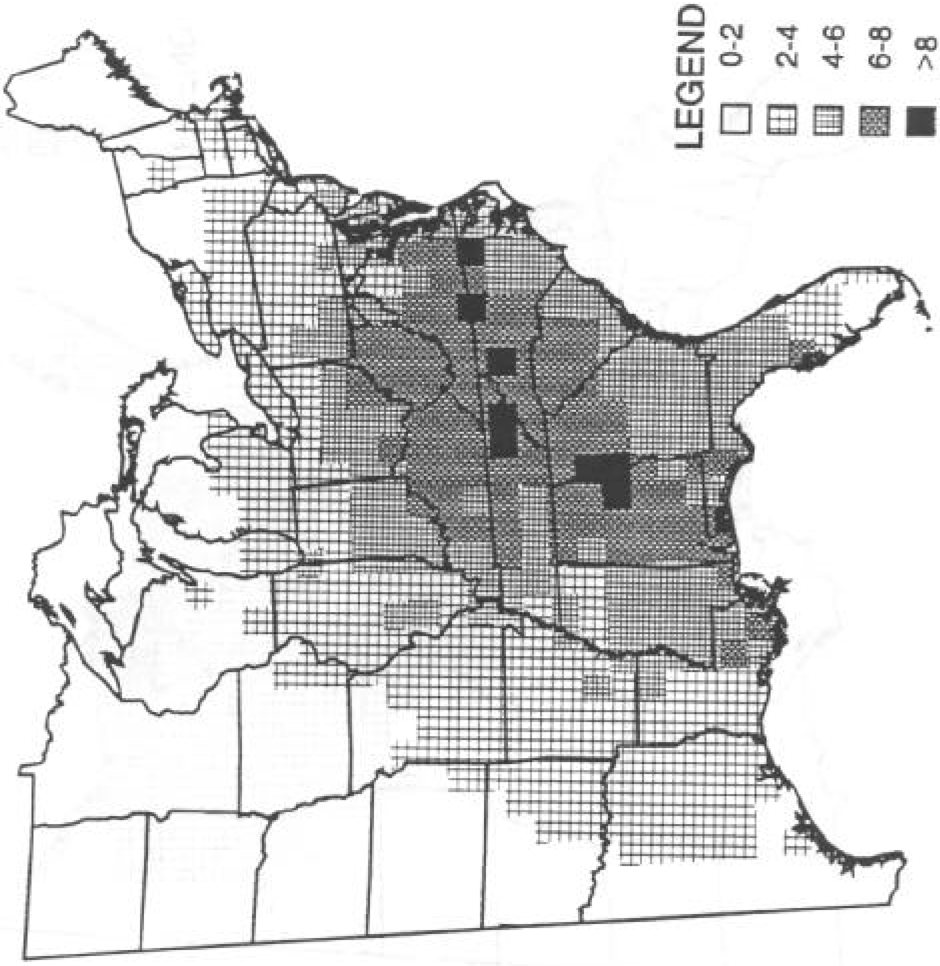
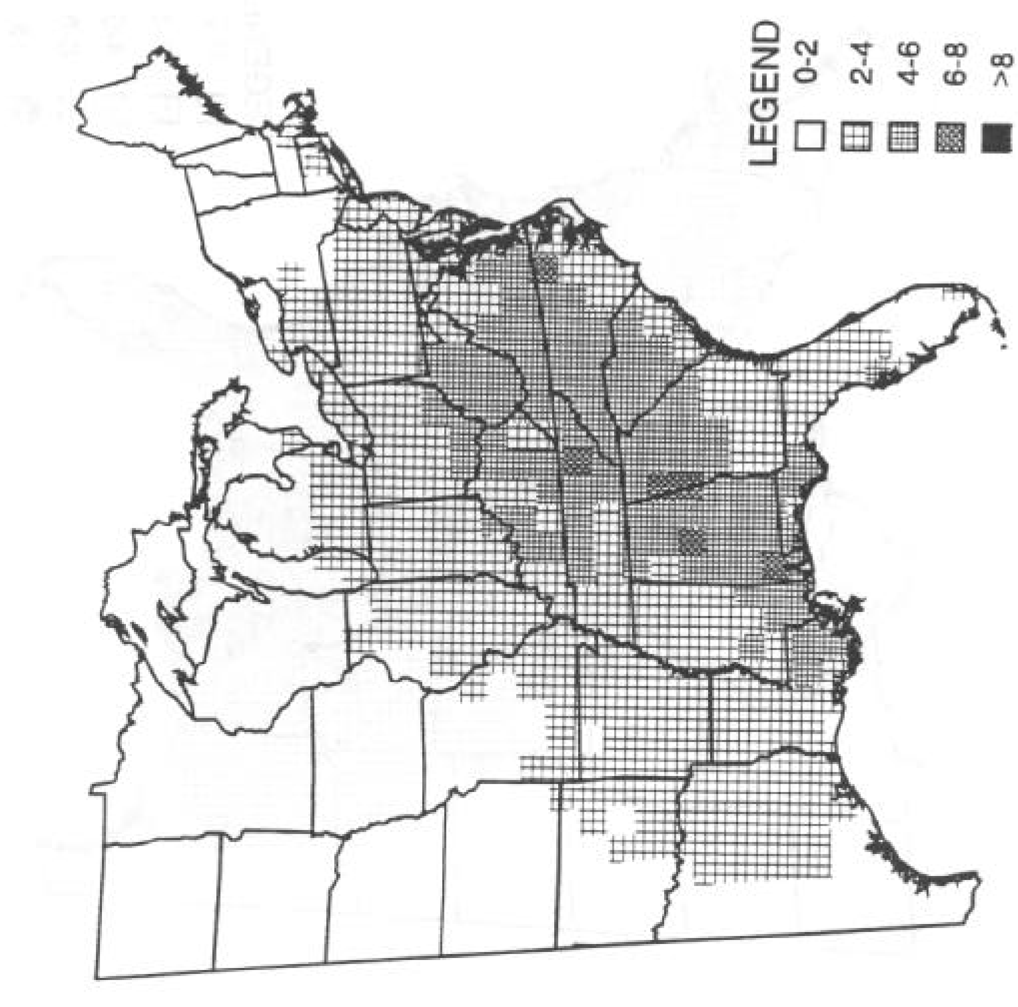


Figure 3-5
RADM 50th Percentile Annual Sulfate Concentration ($\mu g/m^3$)
2010 with Title IV



For the U.S., the latitude-longitude coordinates for each centroid of each census block group, as provided on U.S. Census Summary Tape File 3A, were then located on the RADM grid. For Canada, the latitude-longitude coordinates for each centroid of each enumeration area, as provided by MapInfo Corp. under license from Statistics Canada, were then located on the RADM grid. Total population, divided into relevant age groupings for the health effects calculations, for each block group or enumeration area was assigned to the grid cell within which the block group or enumeration area centroid was located.[1] The error in assuming that all the population is located at the centroid of the block group or enumeration area is small given that the block groups and enumeration areas are small relative to the size of the RADM grid cells. There are about 300,000 block groups in the study area, each with a total population of about 670. An enumeration area usually contains about 125 dwellings in a rural area and 375-400 dwellings in an urban area.

State or province identifiers for each block group or enumeration area were used to sum to state or province[2] level results after health effects estimates were calculated for each RADM grid cell, based on the differences in predicted sulfate concentrations for the cell under different scenarios.

This assessment estimates health benefits for changes in sulfate concentrations in 1997 and in 2010. The 1990 populations are therefore adjusted for expected average population growth using the mid-forecasts of the U.S. Census and the World Bank population projections for Canada. These adjustments are made at the aggregate level using national average population growth factors.

[1] Block group specific age data were used for the U.S. population. For the Canadian population, country average age distributions (Statistics Canada, 1994) were applied uniformly to each enumeration area.

[2] The RADM grid covers virtually all of Ontario's population, but not all of Quebec is covered. The population of Quebec used in the assessment only includes those persons living in enumeration areas covered by the RADM grid. Approximately 99 percent of Quebec's population is included.

Table 3-3
Average Reductions in Median Annual SO_4 Concentrations ($\mu g/m^3$) by State/Province Due to Title IV

State/Province	1997[1]	2010[2]	State/Province	1997	2010
Alabama	0.44	1.93	Mississippi	0.24	1.01
Arkansas	0.22	0.54	Missouri	0.16	0.45
Connecticut	0.35	0.26	New Hampshire	0.21	0.16
Delaware	0.22	0.86	New Jersey	0.22	0.68
District of Columbia	0.30	1.48	New York	0.29	0.34
Florida	-0.02	1.01	North Carolina	0.30	1.73
Georgia	0.31	1.88	Ohio	0.51	1.43
Illinois	0.31	0.80	Pennsylvania	0.44	0.92
Indiana	0.53	1.28	Rhode Island	0.41	0.31
Iowa	0.00	0.21	South Carolina	0.24	1.82
Kentucky	0.86	2.02	Tennessee	0.84	2.09
Louisiana	0.08	0.70	Vermont	0.21	0.20
Maine	0.11	0.15	Virginia	0.42	1.75
Maryland	0.41	1.29	West Virginia	0.72	2.08
Massachusetts	0.24	0.24	Wisconsin	0.03	0.20
Michigan	0.11	0.29	Ontario	0.13	0.13
Minnesota	-0.03	0.05	Quebec	0.09	0.05

[1] The 1997 reduction is estimated versus 1985 emissions.
[2] The 2010 reduction is estimated versus 2010 without Title IV emissions.